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EFFECTS OF AGING ON LEAD SELENIDE DETECTORS

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FOREWORD

The work reported here was performed from January through December 1962 as part of the Joint Services Infrared Sensitive Element Testing Program. It was authorized by WepTask RMGA-41-049/211-1/R008-03-002 and covered by the following funds:

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ABSTRACT

Results are reported of a study made on ten cooled PbSe photoconductive detectors that were stored at an ambient temperature of 22°C ± 2° for periods of from six to eight months. Six of the detectors were evaporated cells produced by the Eastman Kodak Company and operated at dry ice temperatures; four were chemically deposited cells produced by the Santa Barbara Research Center and operated at liquid nitrogen temperatures. A small change in dark resistance appeared to be the only noticeable effect of aging.

INTRODUCTION

Renewed interest has been shown recently in the effects of aging on lead selenide (PbSe) photoconductive detectors. A study was made at this Laboratory of ten cooled PbSe photoconductive detectors that were stored at an ambient temperature of 22°C ± 2° for periods of from six to eight months. Six of the detectors were evaporated cells produced by the Eastman Kodak Company and operated at dry ice temperatures; four were chemically deposited cells produced by the Santa Barbara Research Center and operated at liquid nitrogen temperatures. (See Figure 1.) The results of tests made before and after the aging process are presented in this report.

DESCRIPTION

Each of the Santa Barbara Research Center (SBRC) cells was packed in a "double barrelled" package,[1] a construction designed to facilitate the outgassing of the Dewar flask in which the detectors must be heated, since PbSe films may not be heated in vacuum. By keeping the detectors out of the vacuum, the package also enhances their stability. A conventional Dewar flask is made of Pyrex glass to which two silicon windows are fused. The flask is heated and outgassed on the vacuum system, while an Aquadag coating on the inner tube provides geometrical shielding. An inner stem insert holds the detector and the filter holder; this stem is cemented to the Dewar flask with Silastic rubber to provide a positive seal against the loss or gain of water vapor in the enclosed air. The four SBRC detectors had been stored at high temperatures for several hundred hours prior to being shipped to NOLC.

The history of the Eastman Kodak Company (EK) detectors was not furnished. They were apparently experimental models, and each was mounted in a permanently sealed, evacuated glass Dewar flask.

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[1] R. M. Talley and J. J. Long, "The Cross-Array Lead Selenide Detector," IRIS, Vol. 7, No. 2 (August 1962) pp. 181-185 (SECRET).

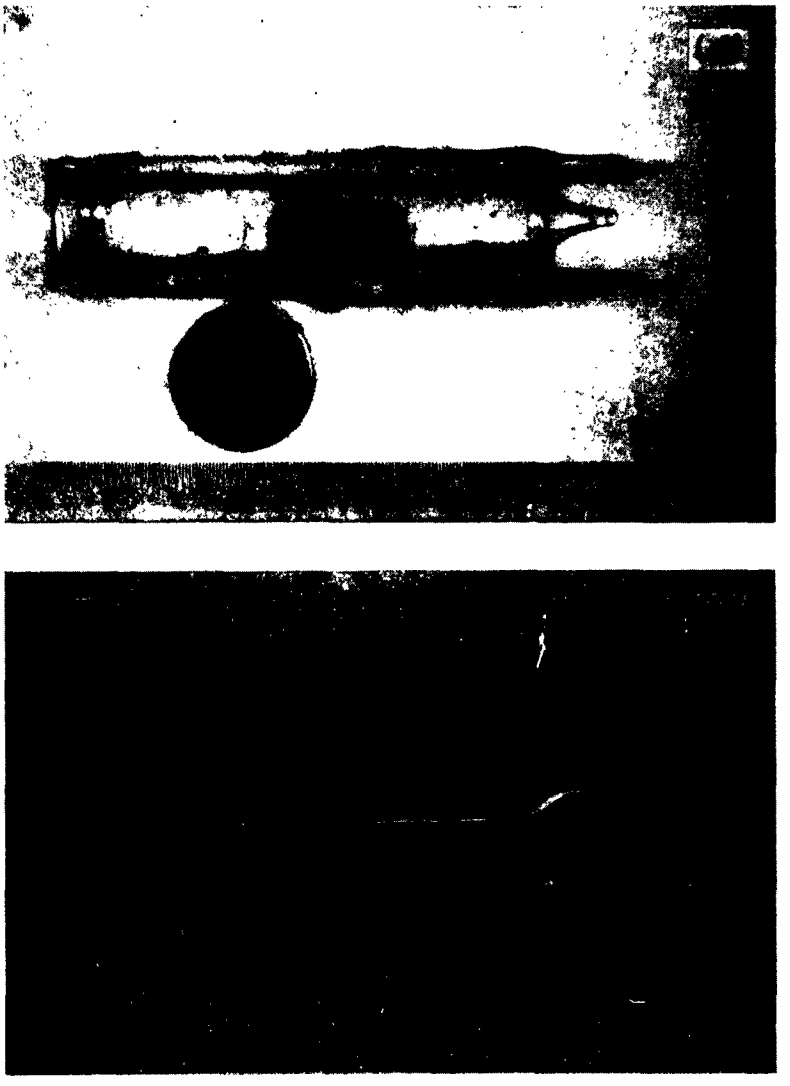

FIGURE 1. Lead Selenide Photoconductive Detectors. (a) EK evaporated cell. (b) SBRC chemically deposited cell.

MEASUREMENT TECHNIQUES

The parameters measured were the signal, relative frequency response, relative spectral response, dark resistance, and noise power spectrum. From these measurements, the various figures of performance were calculated. Appendix 1 contains definitions and descriptions of these figures of performance.[2]

The electronics for the signal and noise measurements consisted of a cathode follower, a modified Tektronix 122 preamplifier, and a General Radio wave-analyzer. The source was a 500°Kelvin blackbody equipped with a 90-cps sinusoidal chopper and water-cooled baffles. The flux density in the plane of the detector was approximately nine microwatts per square centimeter. Noise spectra were obtained for each sample over the frequency range of 20 to 10,000 cps. The detectors were shielded during the noise measurements to insure exposure to ambient radiation only.

The frequency response measurements were obtained on a dynamic system and were continuously frequency-monitored by a Hewlett-Packard Model 500-A tachometer. Data readout was achieved by introducing the two signals into the x and y axes of an oscilloscope and photographing the resulting trace.

A Leiss double monochromator equipped with calcium fluoride prisms was used to measure the spectral response of each detector. The measurements were made on a point-by-point basis; at a given wavelength, the detector was measured first and then the signal from the reference, a Perkin-Elmer radiation thermocouple.

The dark resistance is a dc measurement made with the detector shielded from all but ambient radiation. After the voltage was applied, sufficient time was allowed before making this measurement to allow the detector resistance to stabilize.

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[2] A detailed description of the measurement procedures may be found in Procedures Used in the Study of the Properties of Photodetectors, by W. L. Eisenman, NOLC Report 541 (July 1961).

RESULTS

Although the number of detectors measured is not sufficient to allow a statistical evaluation, some general observations can be made. The results of the dark resistance measurements are included in Table 1 along with calculations of the various figures of performance. Three of the EK evaporated detectors showed a decrease in responsivity of about 20 percent, but the responsivity of the other three EK detectors remained essentially constant. The dark resistance of the evaporated detectors showed a slight increase, the maximum change being about 40 percent, while the dark resistance of the chemically deposited detectors showed a slight decrease, the maximum change being about 20 percent. The frequency response and the spectral response for all the detectors remained unchanged over the storage period. The noise spectra showed varying amounts of 1/f noise, from a predominant amount in the evaporated cells to only a low frequency component in the chemically deposited cells. The noise spectra of all cells measured were found to be unchanged, within experimental error, over the period of aging.

A data sheet and a set of evaluation curves for a detector representative of each type are shown in Figures 2 through 5.

CONCLUSIONS

Although a small change in dark resistance was noted in almost all of the detectors, no significant changes were found in any of the figures of performance.

The evaporated detectors produced by the Eastman Kodak Company showed responsivity and dark resistance results consistent with previous measurements made on other EK lead selenide detectors aged for a somewhat longer period.[3] The stability of the spectral response and noise spectra were better than those obtained in the previous aging studies.

The chemically deposited detectors produced by the Santa Barbara Research Center showed considerable improvement in the stability of all parameters measured in the previous aging studies.[3] This improvement is attributed to the previously described new method of packaging the detectors.

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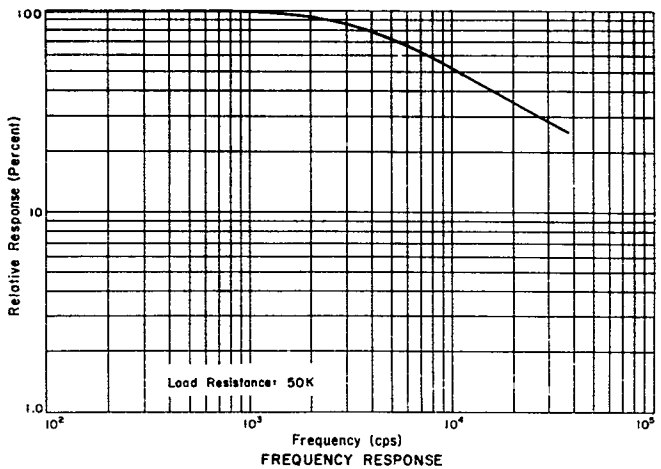
[3] Storage Life of Cooled Lead Selenide Detectors, by W. L. Eisenman, NOLC Technical Memorandum 43-8 (October 1961).

TABLE 1. Summary of Data

Cell type	Cell no.[1]	Area (cm^2)	Cell temp. (°K)	Date tested	Blackbody figures (500, 90)				Dark resistance (ohms)	Responsive time constant (μsec)	$R_{\lambda max}/R_{bb}$	Peak wavelength (μ)	Peak detective modulation frequency (cps)	D^*_{mm} $\left(\frac{cm \cdot cps^{\frac{1}{2}}}{watt}\right)$
					R, responsivity (volts/watt)	H_N, noise equivalent irradiance $\left(\frac{watts}{cps^{\frac{1}{2}} \cdot cm^2}\right)$	P_N, noise equivalent power $(watts/cps^{\frac{1}{2}})$	D* $\left(\frac{cm \cdot cps^{\frac{1}{2}}}{watt}\right)$						
PbSe (evap)	EK J621-19	6.3×10^{-3}	195	1-62	6.4×10^{4}	9.3×10^{-9}	5.8×10^{-11}	1.4×10^{9}	6.7×10^{6}	16	9.3	2.0	1.0×10^{4}	2.2×10^{10}
				9-62	4.2×10^{4}	1.1×10^{-8}	7.1×10^{-11}	1.1×10^{9}	1.1×10^{7}	15	9.3	2.0	$>2.0 \times 10^{4}$	2.2×10^{10}
PbSe (evap)	EK J621-30	6.3×10^{-3}	195	1-62	4.6×10^{4}	5.9×10^{-9}	3.7×10^{-11}	2.1×10^{9}	4.1×10^{6}	28	9.1	2.2	1.0×10^{4}	3.5×10^{10}
				9-62	3.9×10^{4}	5.5×10^{-9}	3.5×10^{-11}	2.3×10^{9}	6.0×10^{6}	25	9.1	2.2	$>4.0 \times 10^{3}$	3.6×10^{10}
PbSe (evap)	EK J621-48	6.3×10^{-3}	195	1-62	4.1×10^{4}	8.8×10^{-9}	5.6×10^{-11}	1.4×10^{9}	1.6×10^{6}	26	9.1	2.2	1.0×10^{4}	2.8×10^{10}
				9-62	3.7×10^{4}	8.1×10^{-9}	5.1×10^{-11}	1.6×10^{9}	3.9×10^{6}	21	9.1	2.2	$>2.0 \times 10^{3}$	2.8×10^{10}
PbSe (evap)	EK 1276	4.9×10^{-1}	195	4-62	2.5×10^{3}	3.6×10^{-9}	1.8×10^{-9}	4.0×10^{8}	4.9×10^{6}	31	7.4	3.3	4.0×10^{3}	1.3×10^{10}
				11-62	2.7×10^{3}	3.7×10^{-9}	1.9×10^{-9}	3.7×10^{8}	4.9×10^{6}	31	7.4	3.3	4.0×10^{3}	1.3×10^{10}
PbSe (evap)	EK 1277	5.6×10^{-3}	195	5-62	1.8×10^{5}	1.5×10^{-8}	8.1×10^{-11}	9.2×10^{8}	3.9×10^{6}	15	6.9	3.1	1.0×10^{4}	3.0×10^{10}
				12-62	2.0×10^{5}	1.5×10^{-8}	8.1×10^{-11}	9.2×10^{8}	4.2×10^{6}	15	6.9	3.1	4.0×10^{3}	2.2×10^{10}
PbSe (evap)	EK 1278	5.6×10^{-3}	195	5-62	1.1×10^{5}	9.0×10^{-9}	5.1×10^{-11}	1.5×10^{9}	2.2×10^{6}	23	8.3	3.2	4.0×10^{3}	4.0×10^{10}
				12-62	1.4×10^{5}	7.9×10^{-9}	4.4×10^{-11}	1.7×10^{9}	2.8×10^{6}	23	8.3	3.2	4.0×10^{3}	3.1×10^{10}
PbSe (chem)	SBRC JW 1278A-36	6.3×10^{-4}	78	4-62	1.8×10^{6}	6.0×10^{-9}	3.8×10^{-12}	6.6×10^{9}	3.5×10^{6}	42	3.9	4.1	$>4.0 \times 10^{3}$	3.9×10^{10}
				10-62	1.7×10^{6}	5.3×10^{-9}	3.3×10^{-12}	7.5×10^{9}	3.0×10^{6}	42	3.9	4.1	$>4.0 \times 10^{3}$	4.6×10^{10}
PbSe (chem)	SBRC JW 1295-7	6.3×10^{-4}	78	4-62	1.3×10^{5}	6.2×10^{-10}	3.9×10^{-11}	6.4×10^{9}	3.5×10^{5}	140	4.1	4.1	$>4.0 \times 10^{3}$	3.3×10^{10}
				10-62	1.4×10^{5}	5.8×10^{-10}	3.6×10^{-11}	6.9×10^{9}	3.5×10^{5}	140	4.1	4.1	$>4.0 \times 10^{3}$	3.8×10^{10}
PbSe (chem)	SBRC 4002-5-13	6.3×10^{-2}	78	4-62	2.5×10^{5}	5.5×10^{-10}	3.4×10^{-11}	7.3×10^{9}	2.0×10^{6}	85	3.9	4.0	$>4.0 \times 10^{3}$	4.3×10^{10}
				12-62	2.7×10^{5}	5.1×10^{-10}	3.2×10^{-11}	7.9×10^{9}	1.9×10^{6}	85	3.9	4.0	$>4.0 \times 10^{3}$	5.0×10^{10}
PbSe (chem)	SBRC 4002-11-13	6.3×10^{-4}	78	4-62	5.8×10^{5}	9.7×10^{-9}	6.0×10^{-12}	4.2×10^{9}	3.8×10^{5}	72	4.4	4.3	$>2.0 \times 10^{3}$	2.1×10^{10}
				10-62	5.3×10^{5}	1.1×10^{-8}	6.5×10^{-12}	3.8×10^{9}	3.3×10^{5}	72	4.4	4.3	$>4.0 \times 10^{3}$	2.2×10^{10}

[1] Abbreviations: EK—Eastman Kodak Co.; SBRC—Santa Barbara Research Center.



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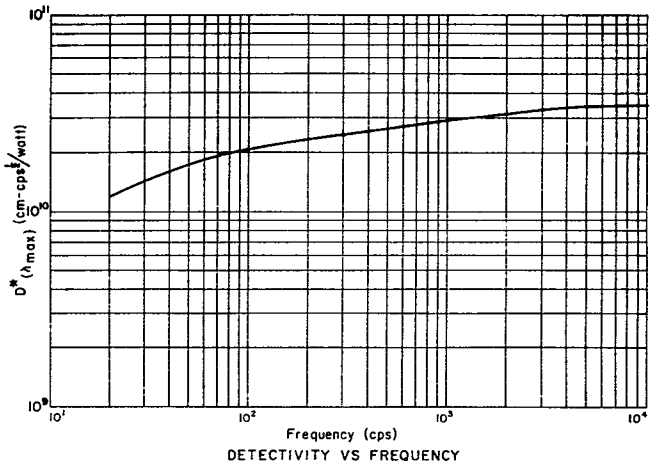
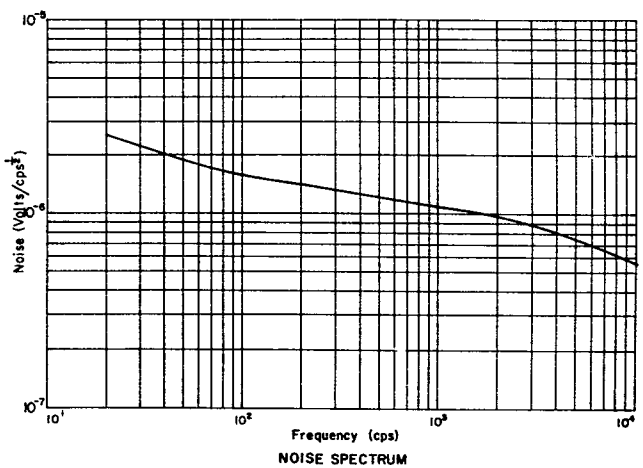


DETECTIVITY VS FREQUENCY



NOISE SPECTRUM

FIGURE 2. Data Obtained From an EK Evaporated Cell in January 1962

TEST RESULTS

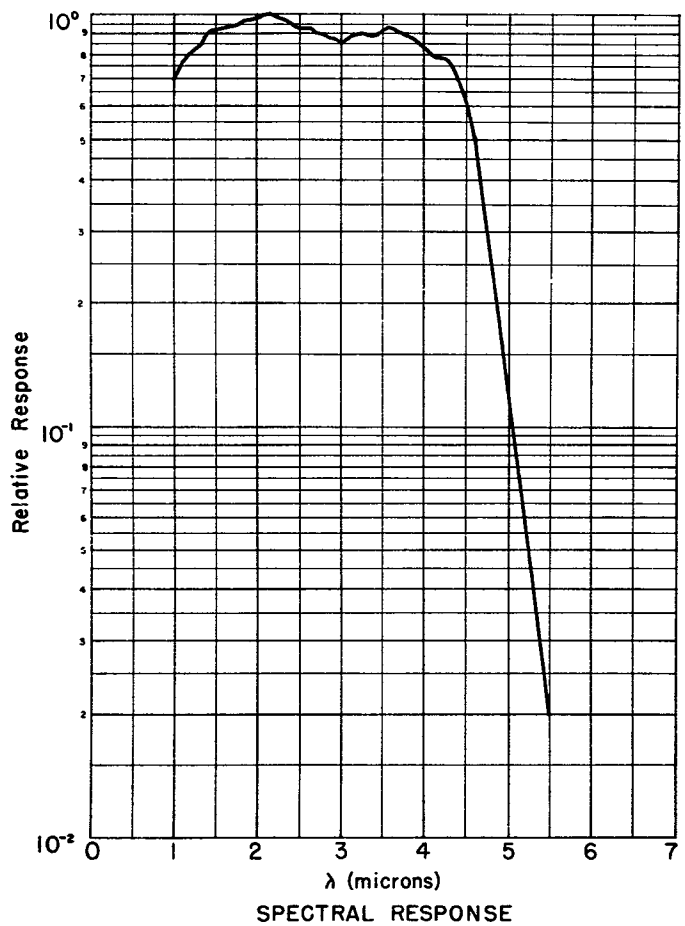
R (volts/watt) (500, 90)	4.6×10^{4}
H_N (watts/cps$^{\frac{1}{2}}$·cm^2) (500, 90)	5.9×10^{-9}
P_N (watts/cps$^{\frac{1}{2}}$) (500, 90)	3.7×10^{-11}
D* (cm·cps$^{\frac{1}{2}}$/watt) (500, 90)	2.1×10^{9}
Responsive time constant (μsec)	28
$\frac{R_{\lambda max}}{R_{bb}}$	9.1
Peak wavelength (μ)	2.2
Peak detective modulation frequency (cps)	1×10^{4}
D^*_{mm} (cm·cps$^{\frac{1}{2}}$/watt)	3.5×10^{10}

CELL DESCRIPTION

Type	PbSe (evap)
Shape of sensitive area (cm)	0.038 x 0.17
Area (cm^2)	6.3×10^{-3}
Dark resistance (ohms)	4.1×10^{6}
Dynamic resistance (ohms)	---
Field of view	---
Window material	Sapphire

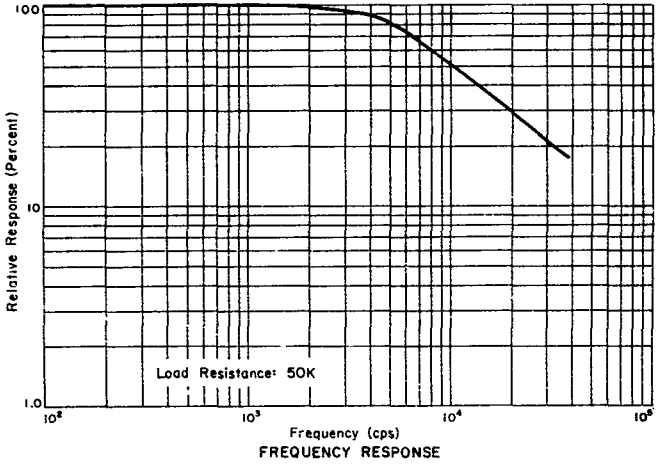
CONDITIONS OF MEASUREMENT

Blackbody temperature (°K)	500
Blackbody flux density (μwatts/cm^2, rms)	9.0
Chopping frequency (cps)	90
Noise bandwidth (cps)	5
Cell temperature (°K)	195
Cell current for 90-cps data (μa)	2.5
Cell current for D^*_{mm} (μa)	2.5
Load resistance (ohms)	2.5×10^{6}
Transformer	---
Relative humidity (%)	26
Responsive plane (from window)	---
Ambient temperature (°C)	24
Ambient radiation on detector	297°K only

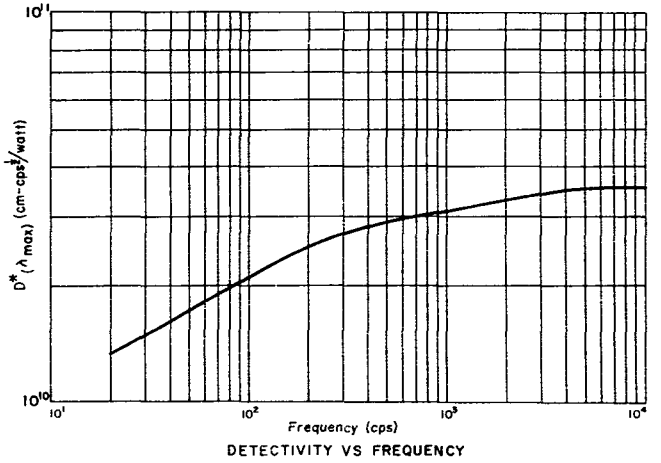


SPECTRAL RESPONSE

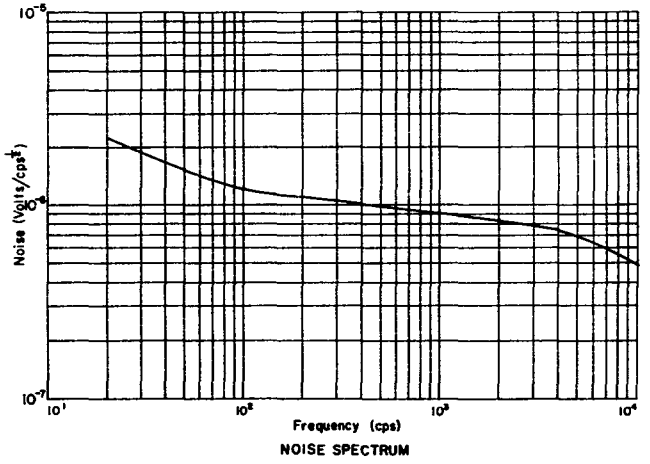
FIGURE 2. (Continued)



FREQUENCY RESPONSE



DETECTIVITY VS FREQUENCY



NOISE SPECTRUM

FIGURE 3. Data Obtained From EK Cell in September 1962, After Aging

TEST RESULTS

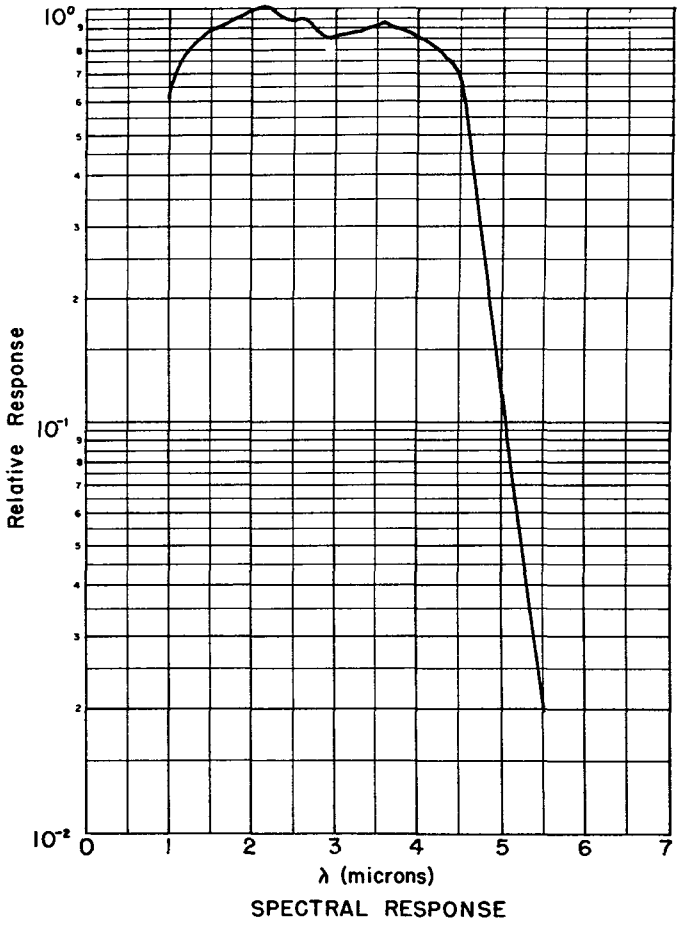
R (volts/watt) (500, 90)	3.9×10^{4}
H_N (watts/cps$^{\frac{1}{2}}$·cm^2) (500, 90)	5.5×10^{-9}
P_N (watts/cps$^{\frac{1}{2}}$) (500, 90)	3.5×10^{-11}
D* (cm·cps$^{\frac{1}{2}}$/watt) (500, 90)	2.3×10^{9}
Responsive time constant (μsec)	25
$\frac{R_{\lambda_{max}}}{R_{bb}}$	9.1
Peak wavelength (μ)	2.2
Peak detective modulation frequency (cps)	$>4 \times 10^{3}$
D^*_{mm} (cm·cps$^{\frac{1}{2}}$/watt)	3.6×10^{10}

CELL DESCRIPTION

Type	PbSe (evap)
Shape of sensitive area (cm)	0.038 x 0.17
Area (cm^2)	6.3×10^{-3}
Dark resistance (ohms)	6.0×10^{6}
Dynamic resistance (ohms)	---
Field of view	---
Window material	Sapphire

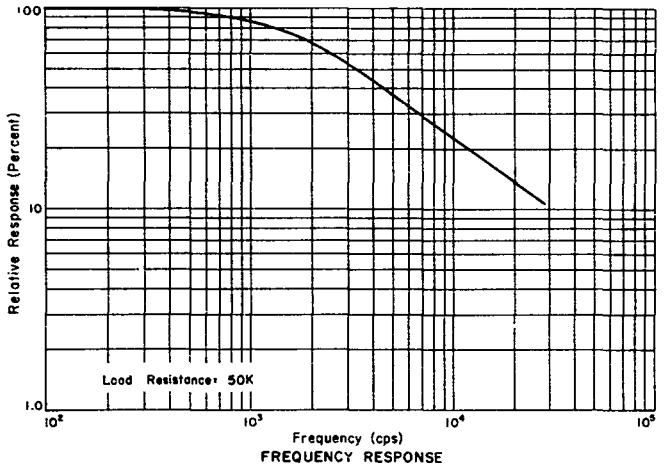
CONDITIONS OF MEASUREMENT

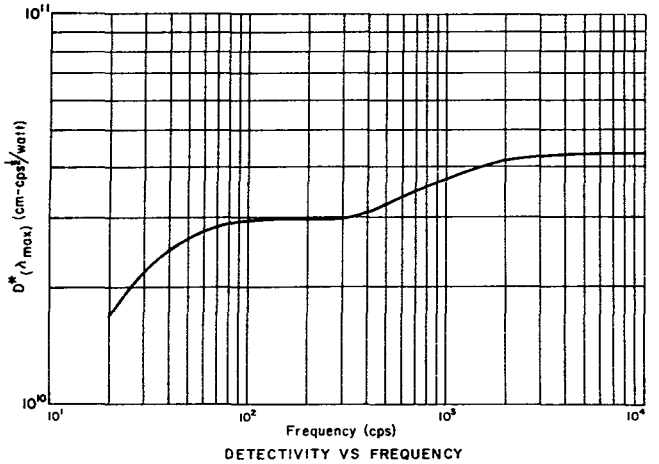
Blackbody temperature (°K)	500
Blackbody flux density (μwatts/cm^2, rms)	9.0
Chopping frequency (cps)	90
Noise bandwidth (cps)	5
Cell temperature (°K)	195
Cell current for 90-cps data (μa)	2.5
Cell current for D^*_{mm} (μa)	2.5
Load resistance (ohms)	2.5×10^{6}
Transformer	---
Relative humidity (%)	39
Responsive plane (from window)	---
Ambient temperature (°C)	23
Ambient radiation on detector	297°K only



SPECTRAL RESPONSE

FIGURE 3. (Continued)





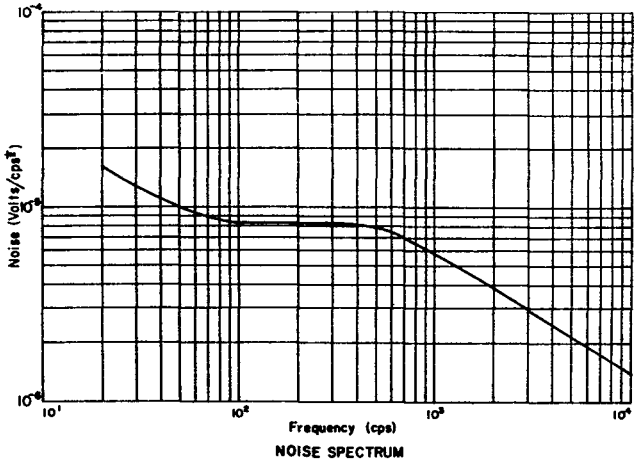


FIGURE 4. Data Obtained From an SBRC Chemically Deposited Cell in April 1962

TEST RESULTS

R (volts/watt) (500, 90)	2.5×10^{5}
H_N (watts/cps$^{\frac{1}{2}}$·cm^2) (500, 90)	5.5×10^{-10}
P_N (watts/cps$^{\frac{1}{2}}$) (500, 90)	3.4×10^{-11}
D* (cm·cps$^{\frac{1}{2}}$/watt) (500, 90)	7.3×10^{9}
Responsive time constant (μsec)	85
$\frac{R_{\lambda_{max}}}{R_{bb}}$	3.9
Peak wavelength (μ)	4.0
Peak detective modulation frequency (cps)	$>4 \times 10^{3}$
D^*_{mm} (cm·cps$^{\frac{1}{2}}$/watt)	4.3×10^{10}

CELL DESCRIPTION

Type	PbSe (chem)
Shape of sensitive area (cm)	0.25 x 0.25
Area (cm^2)	6.25×10^{-2}
Dark resistance (ohms)	2.0×10^{6}
Dynamic resistance (ohms)	---
Field of view	53°
Window material	Silicon (coated)

CONDITIONS OF MEASUREMENT

Blackbody temperature (°K)	500
Blackbody flux density (μwatts/cm^2, rms)	9.0
Chopping frequency (cps)	90
Noise bandwidth (cps)	5
Cell temperature (°K)	78
Cell current for 90-cps data (μa)	100
Cell current for D^*_{mm} (μa)	100
Load resistance (ohms)	1.0×10^{6}
Transformer	---
Relative humidity (%)	36
Responsive plane (from window)	---
Ambient temperature (°C)	24
Ambient radiation on detector	297°K only

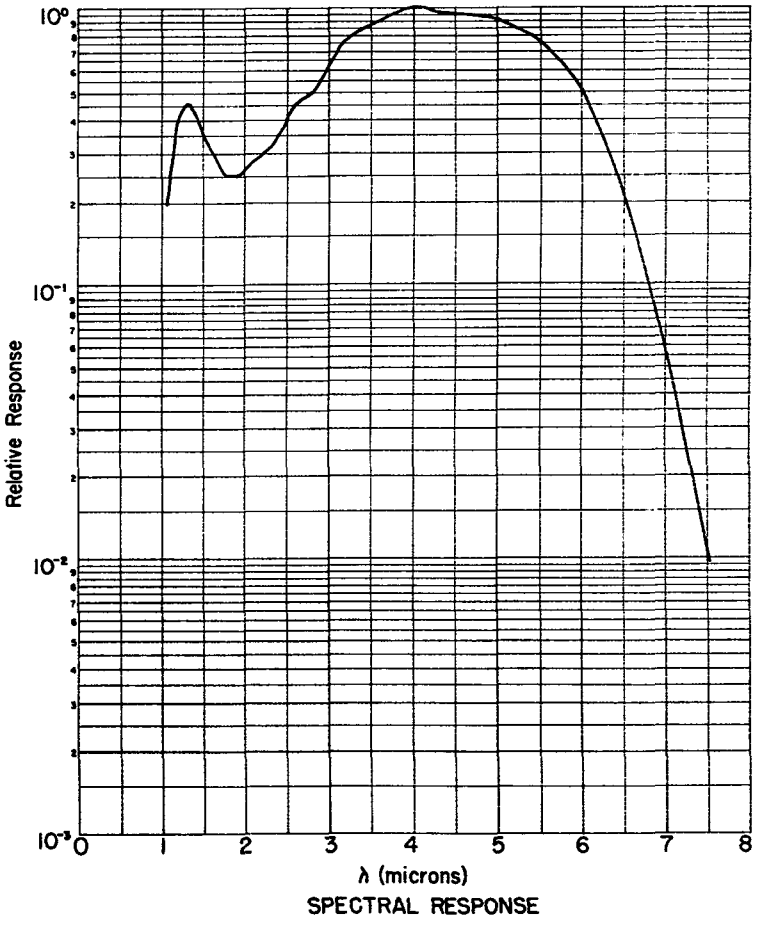
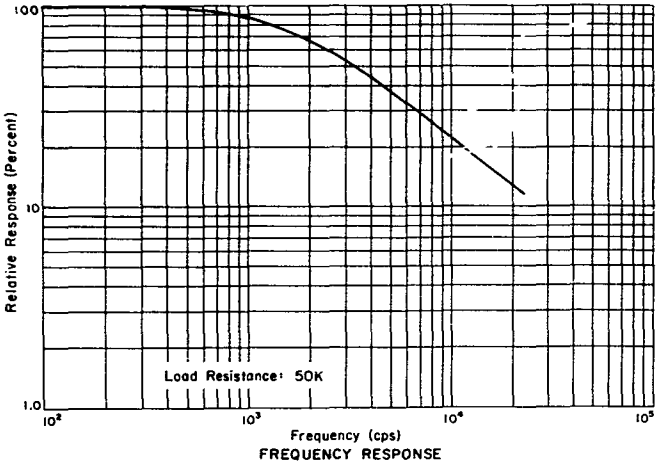
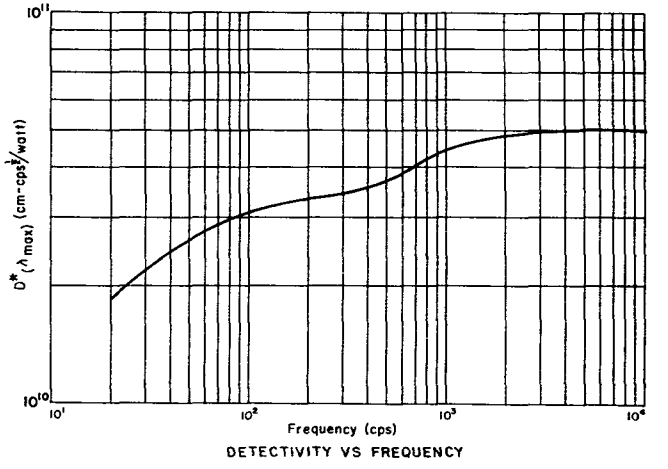


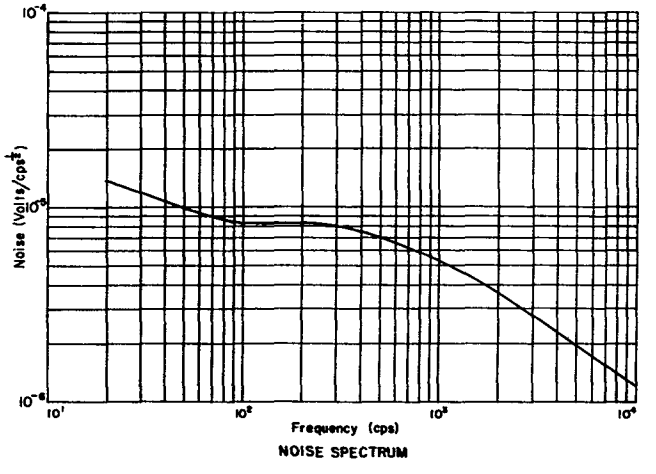
FIGURE 4. (Continued)



FREQUENCY RESPONSE



DETECTIVITY VS FREQUENCY



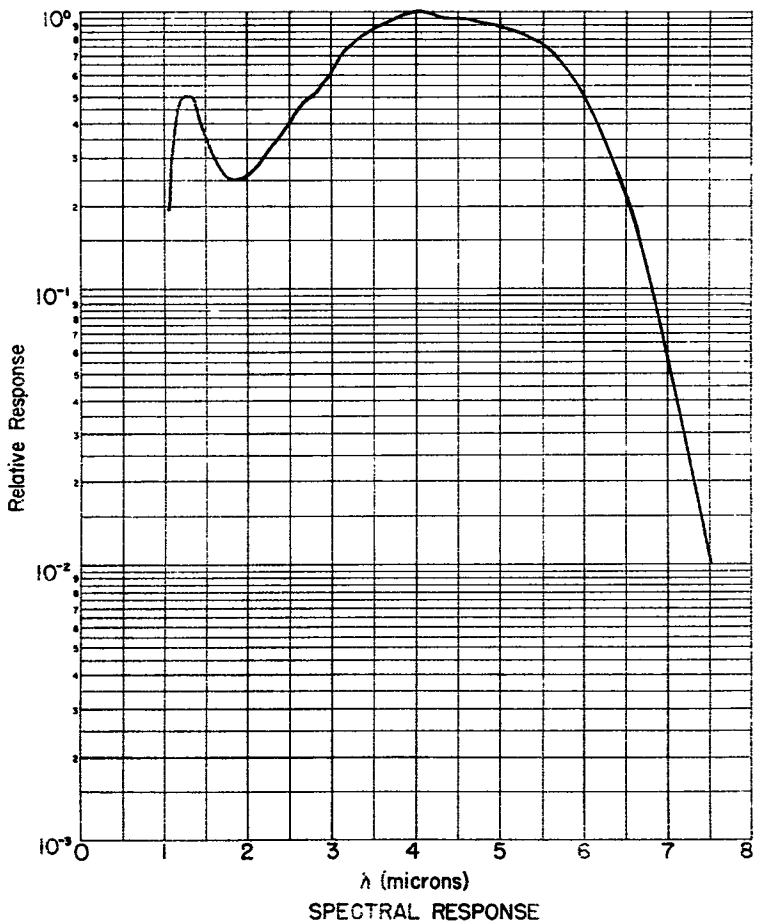
NOISE SPECTRUM

FIGURE 5. Data Obtained From SBRC Cell in December 1962, After Aging

TEST RESULTS	
R (volts/watt) (500, 90)	2.7×10^{5}
H_N (watts/cps$^{\frac{1}{2}}$·cm^2) (500, 90)	5.1×10^{-10}
P_N (watts/cps$^{\frac{1}{2}}$) (500, 90)	3.2×10^{-11}
D* (cm·cps$^{\frac{1}{2}}$/watt) (500, 90)	7.9×10^{9}
Responsive time constant (μsec)	85
$\frac{R_{\lambda_{max}}}{R_{bb}}$	3.9
Peak wavelength (μ)	4.0
Peak detective modulation frequency (cps)	$>4 \times 10^{3}$
D^*_{mm} (cm·cps$^{\frac{1}{2}}$/watt)	5.0×10^{10}

CELL DESCRIPTION	
Type	PbSe (chem)
Shape of sensitive area (cm)	0.25 x 0.25
Area (cm^2)	6.25×10^{-2}
Dark resistance (ohms)	1.9×10^{6}
Dynamic resistance (ohms)	---
Field of view	53°
Window material	Silicon (coated)

CONDITIONS OF MEASUREMENT	
Blackbody temperature (°K)	500
Blackbody flux density (μwatts/cm^2, rms)	9.0
Chopping frequency (cps)	90
Noise bandwidth (cps)	5
Cell temperature (°K)	78
Cell current for 90-cps data (μa)	100
Cell current for D^*_{mm} (μa)	100
Load resistance (ohms)	1.0×10^{6}
Transformer	---
Relative humidity (%)	29
Responsive plane (from window)	---
Ambient temperature (°C)	23
Ambient radiation on detector	297°K only



SPECTRAL RESPONSE

FIGURE 5. (Continued)

APPENDIX

DEFINITIONS OF SYMBOLS AND TERMS

A = adopted sensitive area of the detector in cm^2

f = modulation frequency of the radiation incident on the detector

Δf = frequency bandwidth of the electrical measuring system in cps

J = rms value of the fundamental component of the radiant energy flux density, in watts/cm^2

N = rms noise voltage

R_0 = maximum response

R_ω = response as a function of $\omega = 2\pi f$

$\frac{R_{\lambda\,max}}{R_{bb}}$ = ratio of the responsivity at the peak wavelength to the responsivity to blackbody radiation

V = rms value of the fundamental component of the signal voltage as measured with the entire surface of the detector exposed

T, responsive time constant. When the photon-excited carriers in the semiconductor have a simple decay mechanism, the response to a sinusoidal varying signal may be given by

$$R_\omega/R_0 = (1 + \omega^2 T^2)^{-\frac{1}{2}}$$

The responsive time constant (T) is calculated from the frequency response. It will be noted that the load resistance used in each case is given on the frequency response curve.

R. The responsivity (R) is defined as the ratio of the rms value of the fundamental component of the signal voltage to the rms value of the fundamental component of the incident radiation power:

$$R = V/JA$$

The units of R are volts/watt.

H_N. The noise equivalent irradiance (H_N) is defined as the minimum radiant flux density necessary to give a signal-to-noise ratio of 1 when the noise is normalized to unit bandwidth:

$$H_N = JN/V \cdot \Delta f^{\frac{1}{2}}$$

The units of H_N are watts/cps$^{\frac{1}{2}}$·cm^2.

P_N. The noise equivalent power (P_N) is defined as the minimum radiant flux necessary to give a signal-to-noise ratio of 1 when the noise is normalized to unit bandwidth:

$$P_N = JNA/V \cdot \Delta f^{\frac{1}{2}}$$

The units of P_N are watts/cps$^{\frac{1}{2}}$.

D*. D-star is defined[1] as the detectivity normalized to unit area and unit bandwidth. Detectivity is the signal-to-noise ratio produced with unit radiant flux incident on the detector:

$$D^* = A^{\frac{1}{2}}/P_N$$

The units of D* are cm·cps$^{\frac{1}{2}}$/watt.

D^*_{mm} is defined as D-star at the peak wavelength, the optimum bias value, and the peak detective modulation frequency.

Calibration. The gain of the electrical system is calibrated by injecting a known voltage in series with the detector being tested. This is accomplished by means of a small resistor placed between the detector ground terminal and the system ground. Thus, the detector signal and noise voltages are referred to the detector terminals and to an infinite load impedance. The detector noise is corrected for amplifier noise.

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[1] R. Clark Jones, "Methods of Rating the Performance of Photoconductive Cells," Proceedings of IRIS, Vol. 2, No. 1, June 1957.

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